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BEAM PROFILE OF THE ADVANCED TEST ACCELERATOR UNDER LASER-ION GUIDING

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DISCLAIMER

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Abstract

Laser-ion guiding is currently deployed on the Advanced Test Accelerator (ATA). Beam profiles are measured as a function of time by detecting optical emissions from foils inserted into the beam path. The beam size is observed to grow with time into the pulse. Two other experimental measurements support this observation: 1) vacuum expansion of the beam shows a loss of current in the latter part of the pulse; 2) beam transport through a pipe of reduced diameter results in a similar loss of current in the tail. These observations of increasing beam size are contrary to expectations based on increasing focus strength due to beam-induced ionization. Possible explanations will be presented.

Introduction

The technique of laser ion-channel guiding [1] is presently deployed on ATA to guide and focus the electron beam through and beyond the accelerator. A number of accompanying papers are presented at this conference to describe and discuss topics concerning this method. This paper presents experimental observations showing that the beam size grows with time into the pulse, indicating emittance growth. This is contrary to expectations based on an increase in focus strength due to beam-induced ionization.

Experimental Observations

Profile Measurement

Beam profiles are measured as a function of time by inserting a target foil and measuring the optical emissions using a gated image-intensifier 2-D camera. This technique is described in a companion paper [2]. A measurement has been performed at the entry carbon foil of the shuttle dump. The time evolution of the beam size is shown in Fig. 1. The beam head starts out at 0.6 cm diameter, and increases to 2 cm diameter by the end of the pulse. This observation implies emittance growth during the pulse.

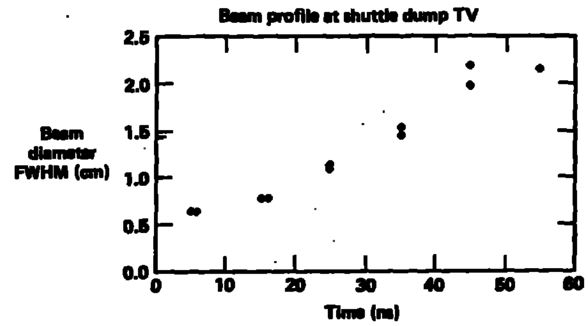

Fig. 1. Time dependence of ATA beam profiles measured using optical emissions from a target foil.

Vacuum Expansion

In a separate experiment benzene gas in the accelerator is stopped at the output end by a thin carbon foil placed in the beamline. The electron beam passes through the foil and is allowed to expand freely in vacuum along the beamline. The beam current is measured using wall return-current monitors at several z locations. Figure 2 shows traces from two current monitors placed 3.6 m apart. It shows that the major portion of the beam head is transported but part of the body and tail is lost to the wall. This loss signifies an increasing emittance through the pulse.

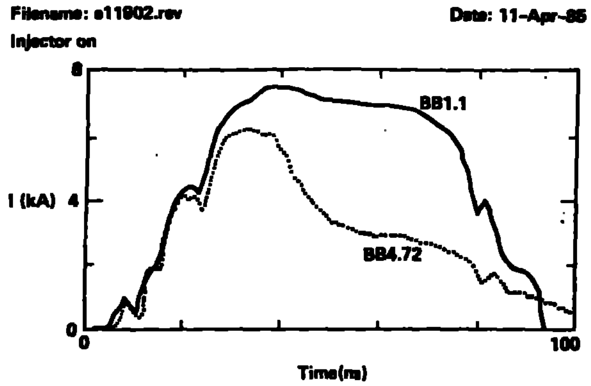

Fig. 2. ATA vacuum expansion experiment showing current loss from the second half of the pulse over a distance of 3.6 m.

Laser-produced Current

Electron current can be obtained at the ATA output even when the cathode emission is turned off. Laser-benzene ionization produces free electrons at essentially zero temperature all along the accelerator. These electrons are swept along the accelerator by the voltage pulse, leading to a beam with low emittance but large energy spread. For comparison to Fig. 2, Fig. 3 shows corresponding traces for the laser-produced current. No loss in pulse current is observed except for a maximum of 25% at the tail. Another 2.2 m further downstream, current is preserved over a distance of 1.2 m between current monitors (Fig. 4).

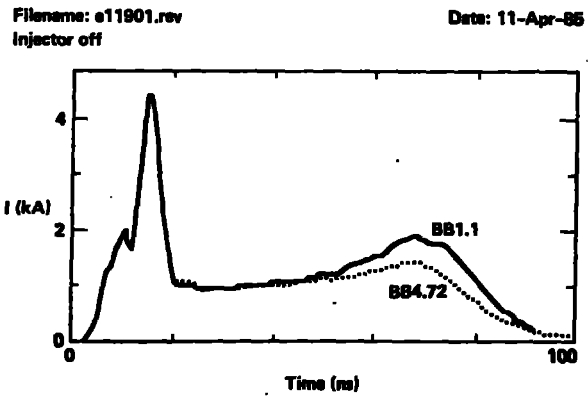

Fig. 3. ATA vacuum expansion experiment for laser-produced current showing current loss only at the tail of the pulse.

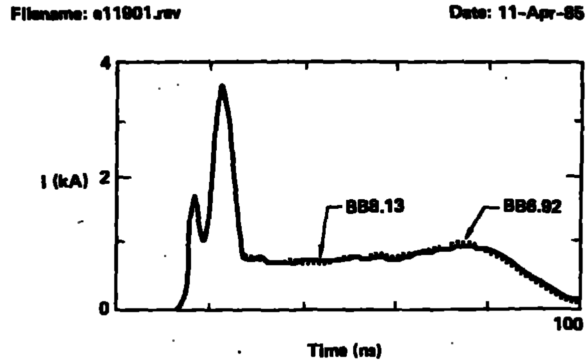

Fig. 4. ATA vacuum expansion experiment for laser-produced current - another 2.2 m further downstream, no current is lost over a distance of 1.2 m.

Transmission through a Reduced-Diameter Pipe

At the output of ATA, the 6.75 cm radius beamline is tapered down to a pipe of 5.0 cm dia and 47 cm length before flaring back to the standard size. It serves to scrap off beam particles at the outer radii as well as to restrict benzene flow downstream. Current monitors before and after the smaller pipe show a loss in the main body growing towards the tail, as shown in Fig. 5. The indication is again that the emittance is increasing towards the tail of the pulse.

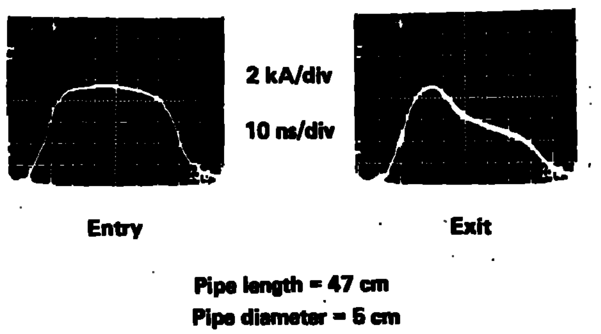

Fig. 5. ATA current loss through a pipe of reduced-diameter is observed in the body and tail of the pulse.

Possible Explanations

Time-Dependent Ion Density

When a uniform laser produces an ionized channel, the ions are initially stationary and uniform in density. An electron beam arriving on axis into this low pressure ion-focused regime immediately ejects electrons, leaving the massive ions behind. These ions begin to move radially inward and subsequently oscillate about the axis. The channel starts collapsing into itself, changing the ion density. After several periods of oscillation, the ions have acquired a temperature. The channel settles down to an equilibrium size but the ions are now moving out of phase with a nonuniform radial-density profile. Thus an electron beam which is matched at the head coming onto the channel, will suffer a mismatch in the later part of the pulse, leading to emittance growth.

Ion Sausage Mode

In addition to the above process, the electron beam can vary in current, radius and spatial position with time into the pulse. The ion and electron motions are now closely coupled together so that a growth in emittance of one species may lead to an emittance growth in the other.

Other Sources of Electrons

The laser-produced current is attributed to laser-ionized electrons that are accelerated by the voltage in the gaps all along the accelerator. When the cathode emission is turned on, electrons from the injector constitute the primary beam. These electrons produce additional collisionally induced ionization. The ionized electrons are ejected by the primary beam leaving an attractive force on the beam. It is possible that electrons are drawn from gap edges and corners during the voltage pulse and accelerated along with the primary beam. This would appear as an increased emittance during the later half of the pulse.

Summary

Experimental observations of emittance growth during the beam pulse have been presented for the ATA beam operated under laser ion-channel guiding. These are measurements of time-dependent beam profiles, vacuum expansion current loss, laser-produced current, and current loss through a reduced-diameter pipe. Possible explanations for the emittance growth have been presented, namely a time-dependent ion density, an ion sausage mode and electrons originating from the accelerating cells.

Acknowledgments

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References

[1] D. S. Prono, et al, IEEE Trans. Nucl. Sci. NS-32, 3144 (1985); G. J. Caporaso, Bull. Am. Phys. Soc. 30, 1545 (1985).

[2] Y. P. Chong, R. Kalibjian, J. P. Cornish, J. S. Kallman and D. Donnelly, accompanying paper presented at this conference.